WLS Gasses for High-Pressure Xenon Detectors

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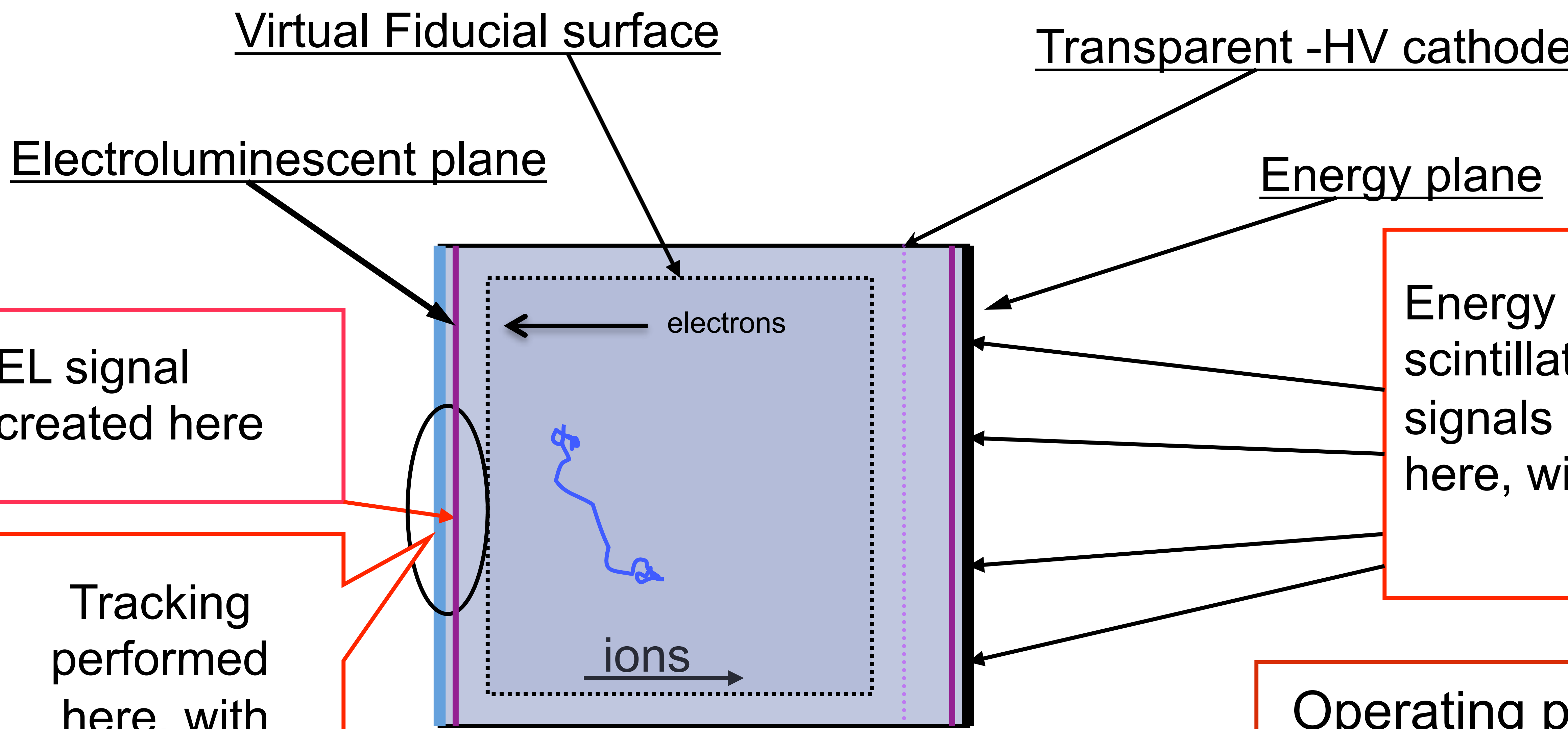
High-Pressure Gas Detectors

- Good for $0\nu\beta\beta$ and for dark matter!
  - Excellent energy resolution (critical for $0\nu\beta\beta$, can also lower threshold for dark matter)
  - Track imaging for high-fidelity track topology (enhanced background rejection)
  - Small charge to light fluctuations (more precisely defined signal and background regions)
  - Can possibly extract nuclear recoil track direction (would be a game changer for dark matter!)

Detector Schematic

Asymmetric TPC *with "Separated functions"*



EL signal created here

Tracking performed here, with "SiPMT" array

Field cage: teflon

Energy & primary scintillation signals recorded here, with PMTs

Operating pressure: 10 -15 bars

Energy Resolution

A. Bolotnikov, B. Ramsey / Nucl. Instr. and Meth. in Phys. Res. A 396 (1997) 360–370

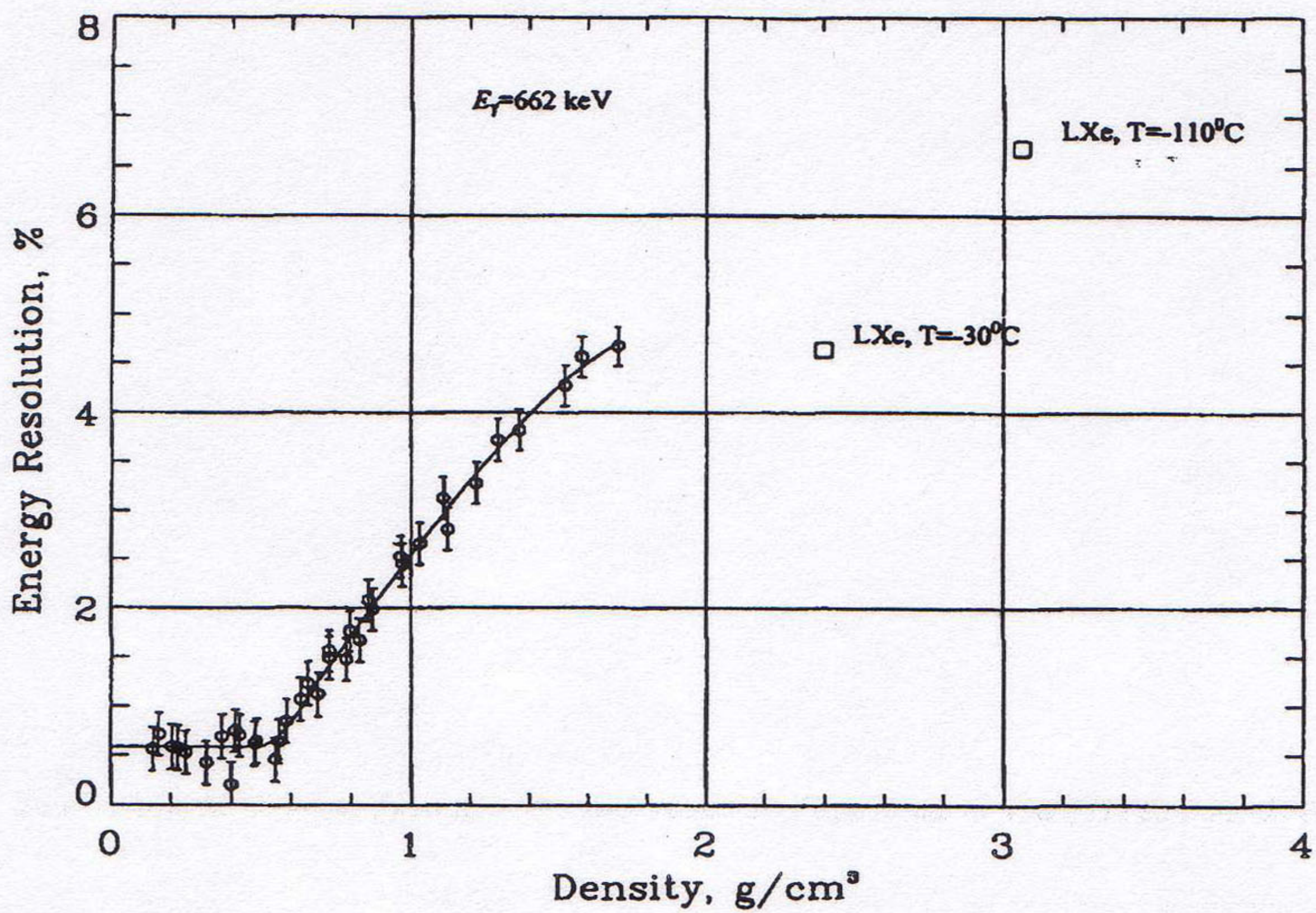
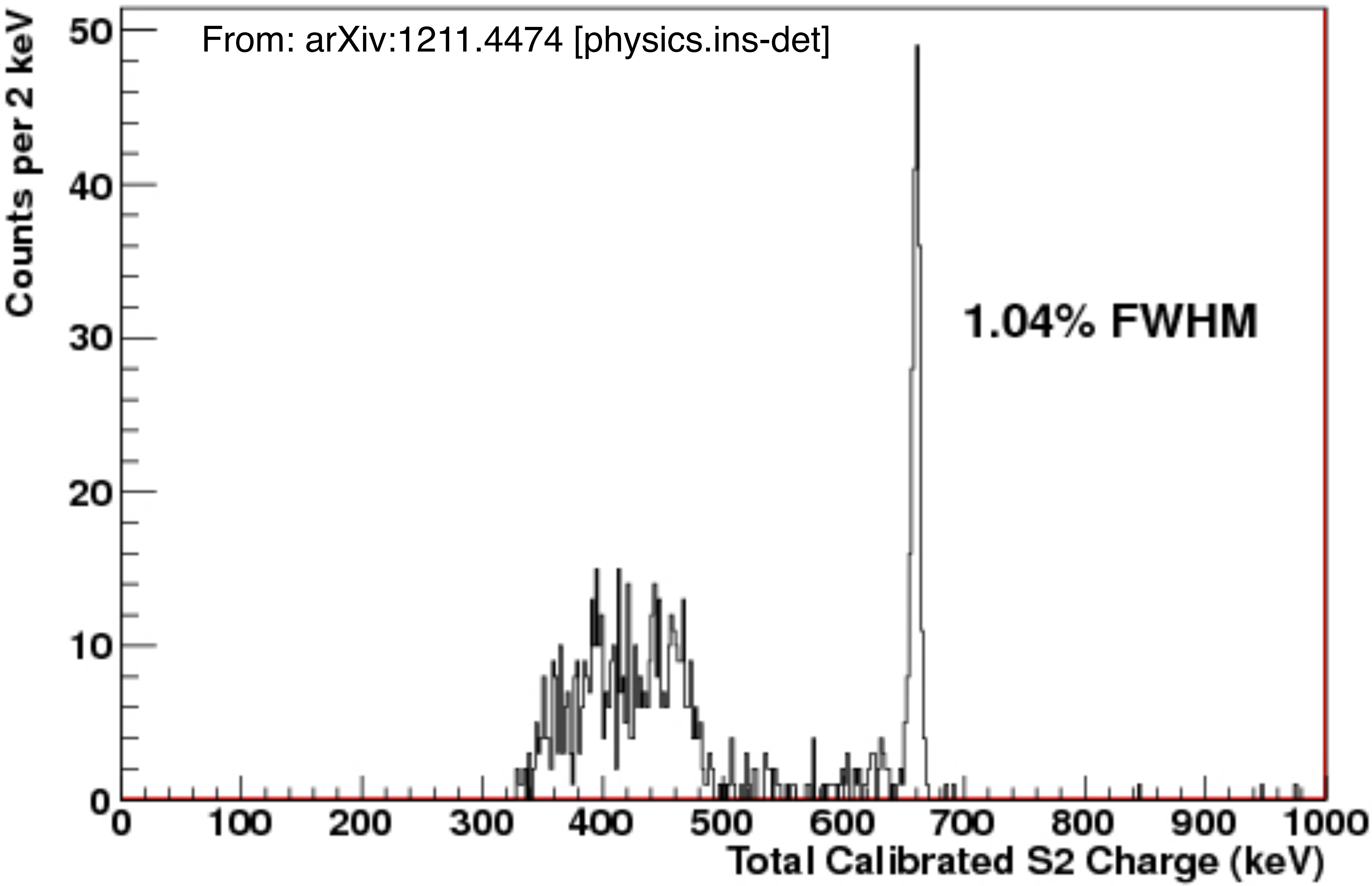


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

A Recent Result!



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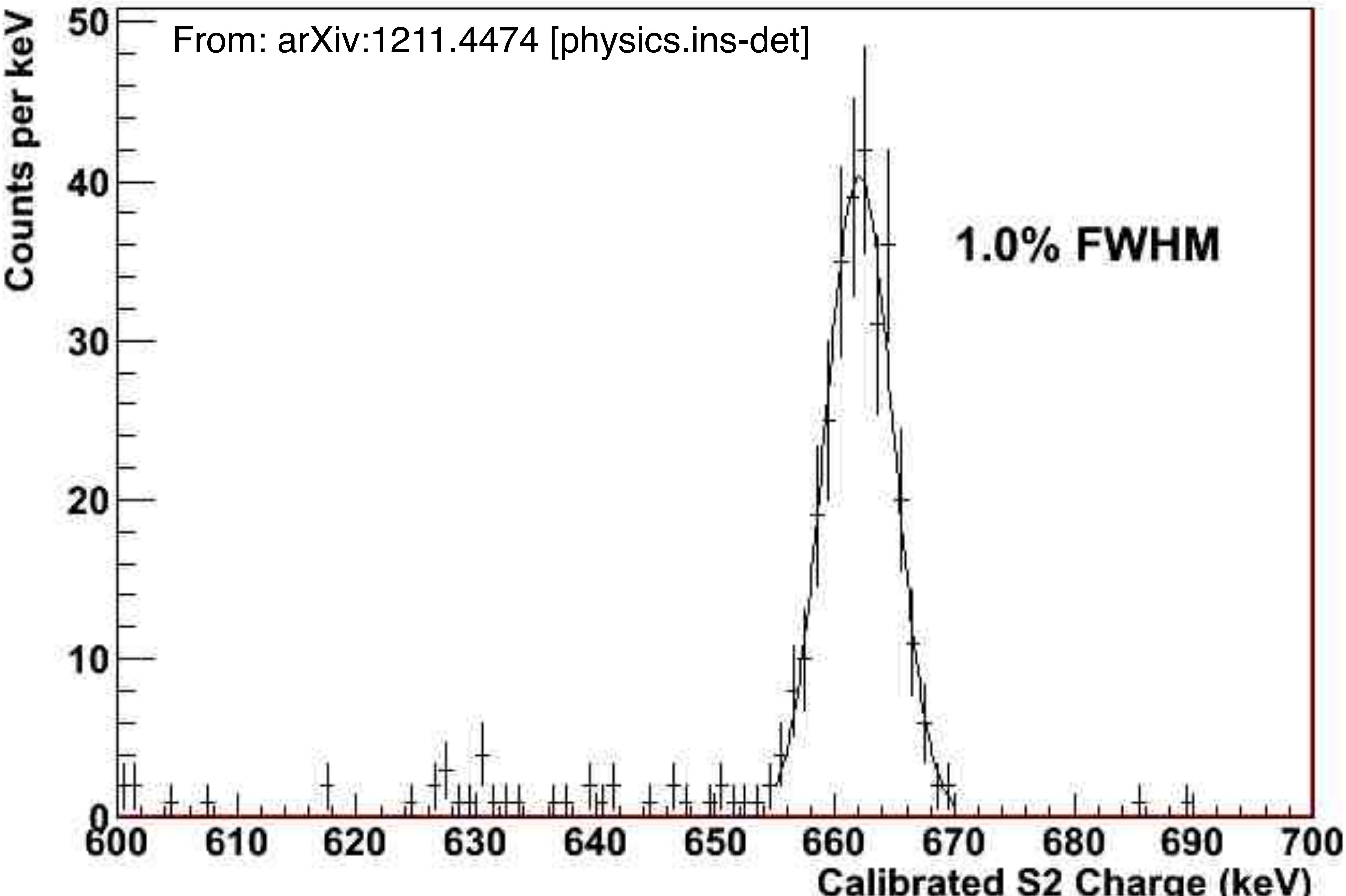
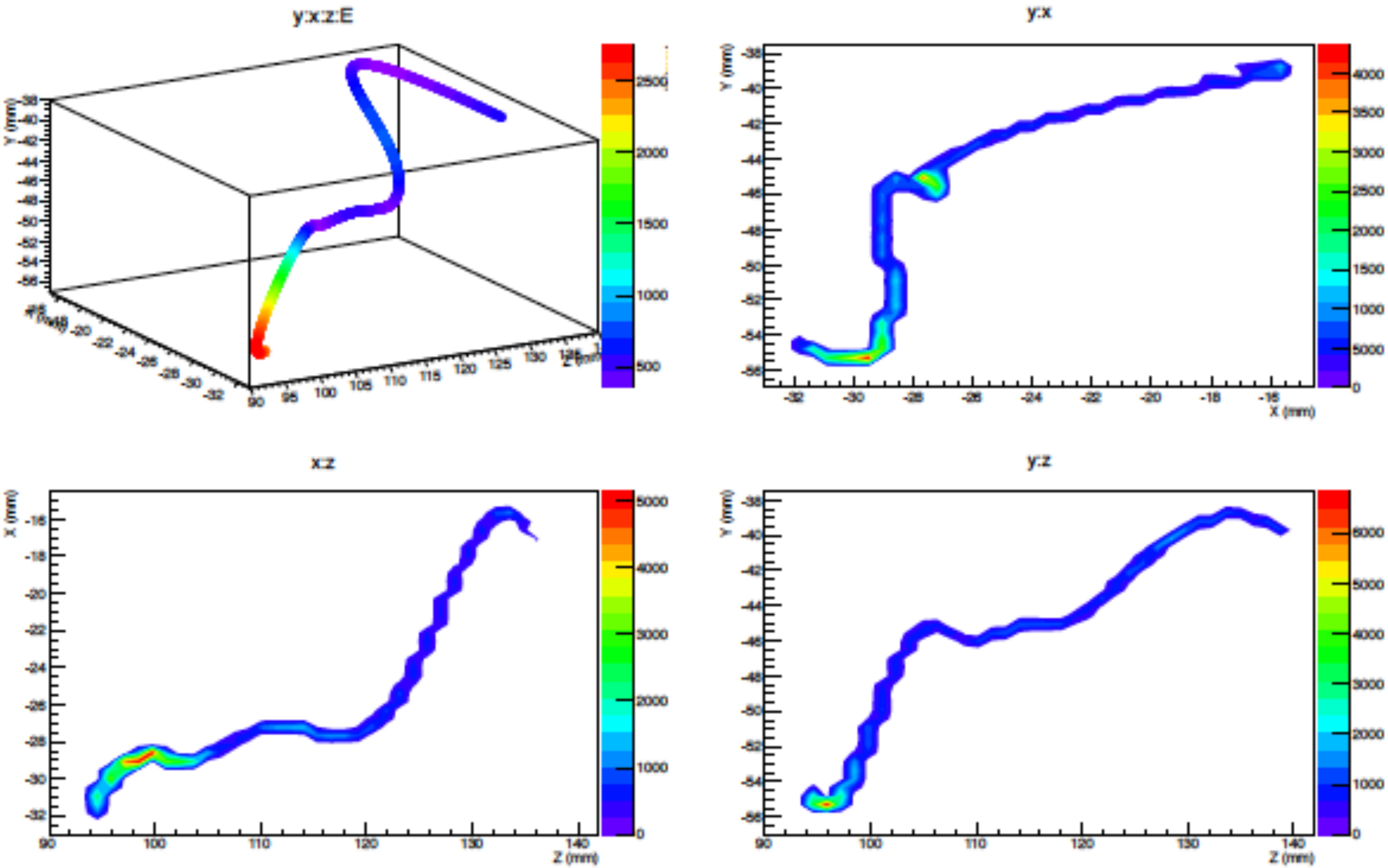


Tracking Too!

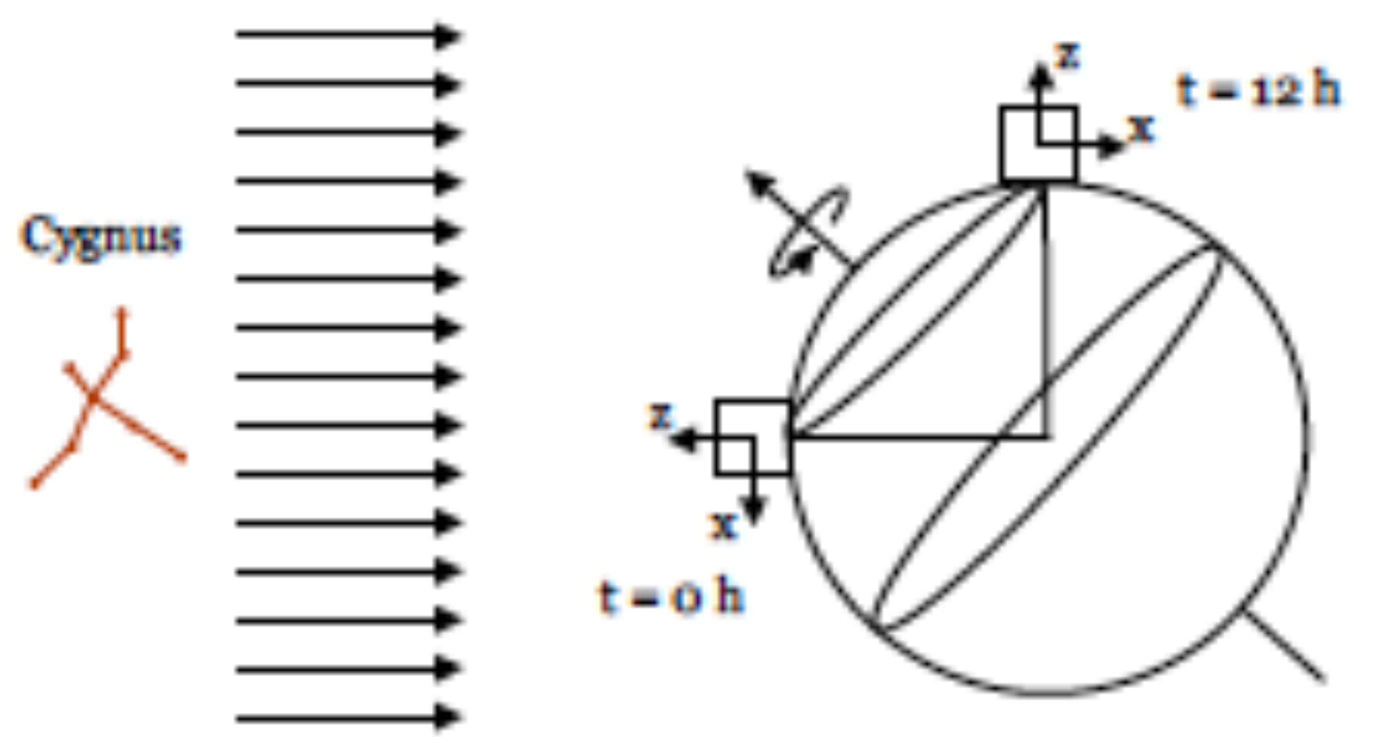
Real track from ^{137}Cs γ-ray – reconstructed with SiPMs



NEXT-DEMO IFIC, Valencia

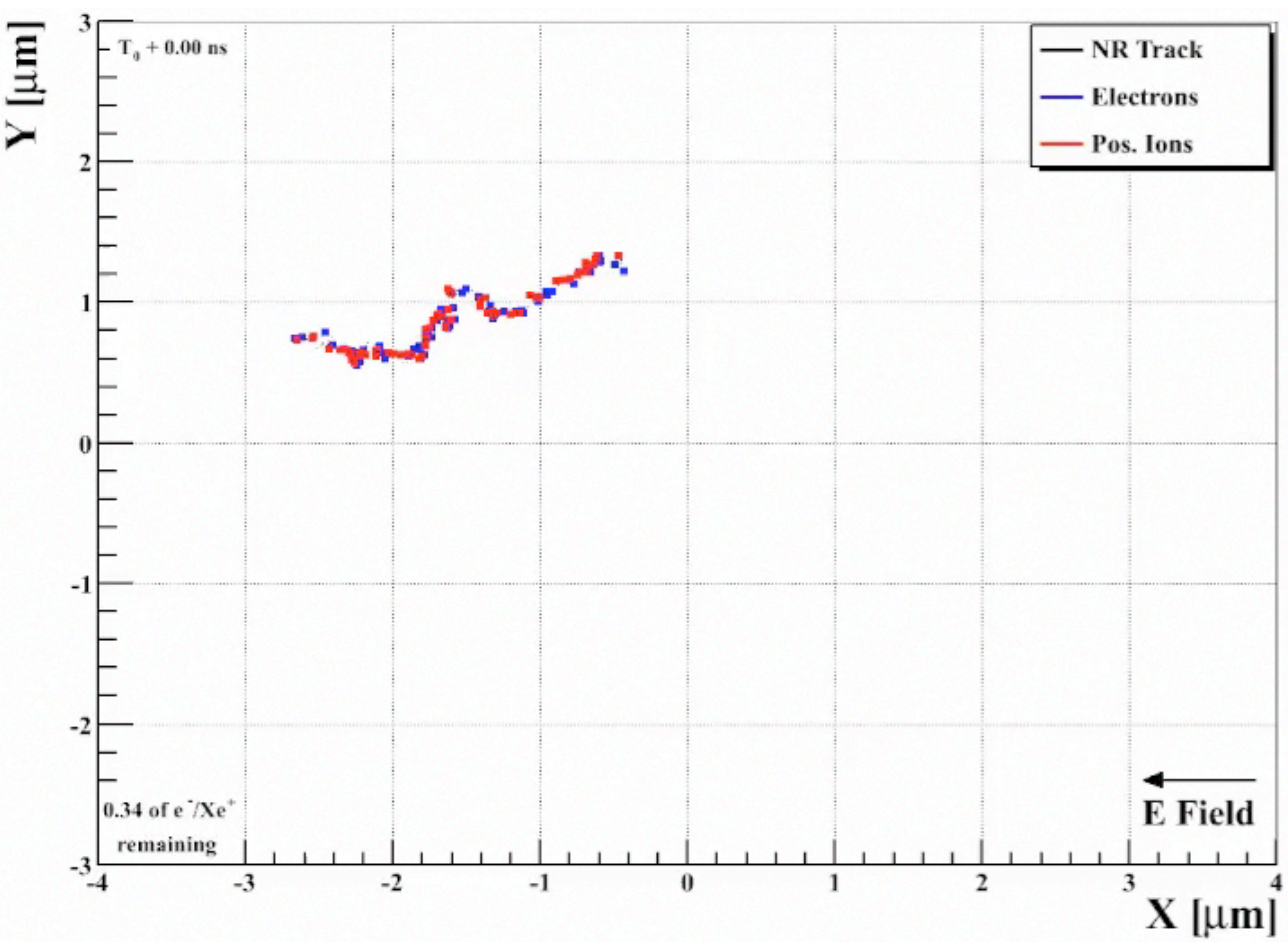
What’s the next step?

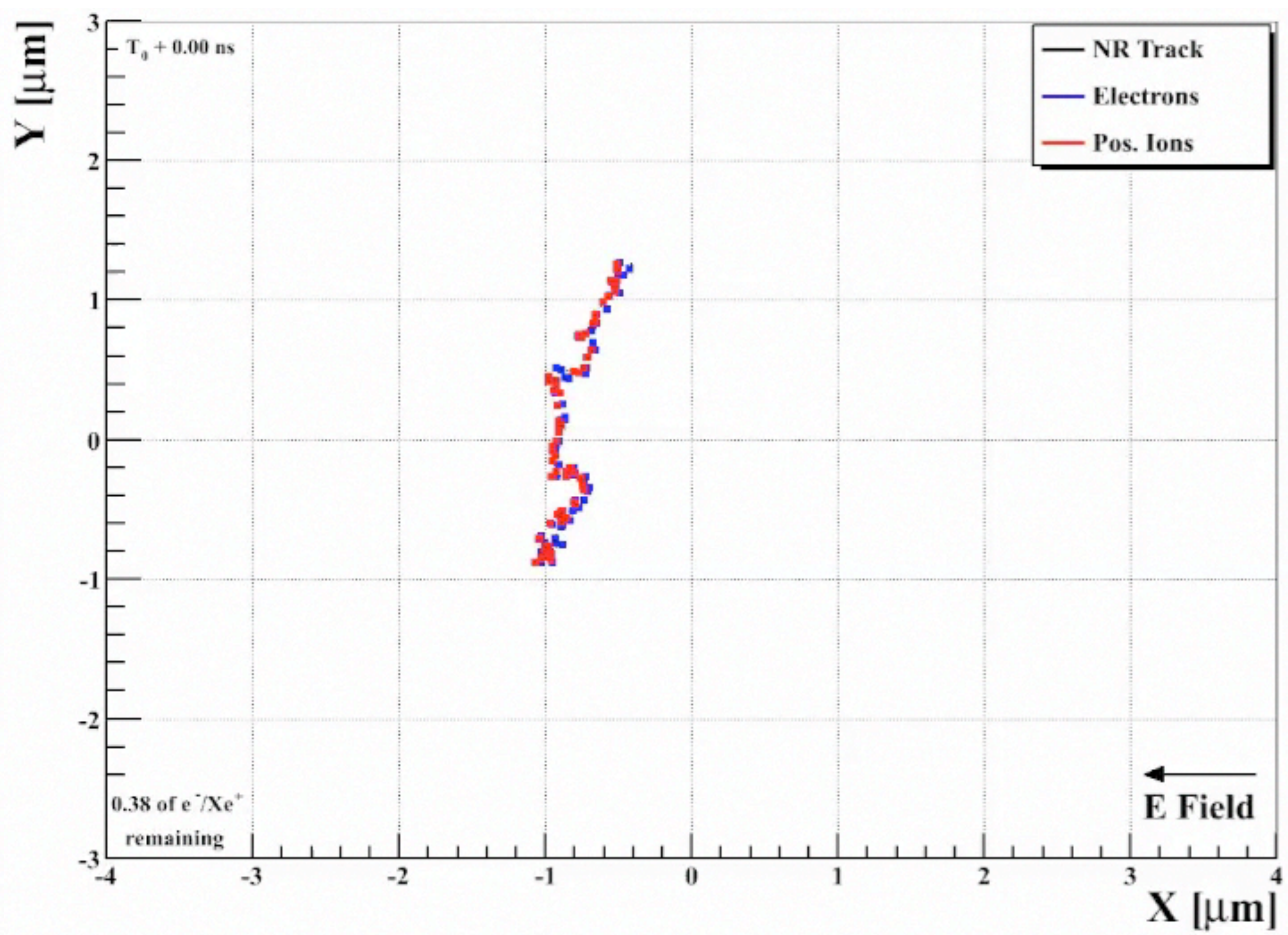
- Previous results were done with pure Xe (tracking plane had evaporated TPB)
- Track directionality would make a very strong case for direct detection of dark matter
- Most current experiments try for directionality by imaging the nuclear recoil track:
    - Very diffuse detectors (low target mass)
    - High energy threshold
    - Poor track image quality



A Different Approach!

- Use *columnar recombination* (CR) to extract track direction...
- Requires ionization electrons drift back through parent track:
  - Depends on angle between drift field and track direction
  - Other recombination types are independent of this angle





How to Maximize This Effect?

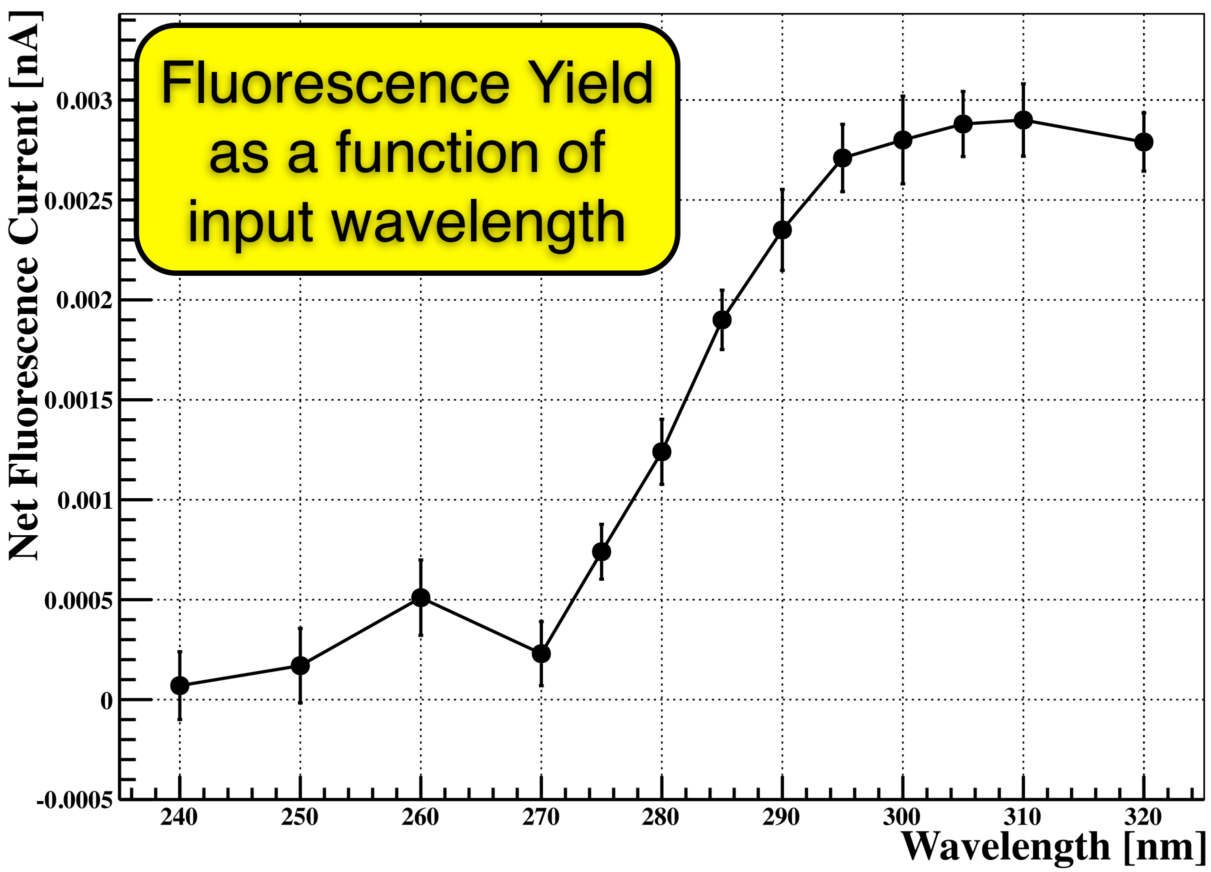
- Define *"Columnarity,"* $C = \dfrac{R}{r_0}$
- Represents the maximal difference in recombination from track angle
- In 0.05 g/cm^3 xenon gas:
  - R ≡ Nuclear recoil track range ≈ 2.1 μm
  - r_0 ≡ Onsager radius (recombination distance) ≈ 70 nm $\quad r_0 = \dfrac{e^2}{\epsilon E_e}$
  - e ≡ electron charge, ε ≡ gas dielectric constant, E_e ≡ electron kinetic energy (usually taken as kT)
  - C ≈ 30 in this case (would like C > 10...)

So What Do We Need?

- We have:
  - Short tracks (~70 nm)... **Don't lose electrons!**
  - Small signals... **Don't waste electrons or photons!**
- Lots of energy deposited form nuclear recoils goes into primary excitations, but...
  - excitations don't contribute to the CR signal!
  - Use the Penning Effect: convert excitons to ions with a molecular additive so that these can contribute to CR too!
- Bonus: the same molecule can cool the electrons, thus increasing the recombination probability

But Wait, There’s More!

- Remember that we are detecting ionization electrons with electro-luminescence light, therefore...
- Poor photon collection efficiency means poor charge collection efficiency!!!
- We can achieve nearly 100% **coverage** if we cover the inside of the TPC with WLS plastic panels read out with PMTs (or APD’s, or SiPMs, *etc.*)
- But most WLS plastic panels are not very efficient in VUV–300 nm light is pretty close to optimal though.
- Must shift 173 nm photons to 300 nm photons in the gas!



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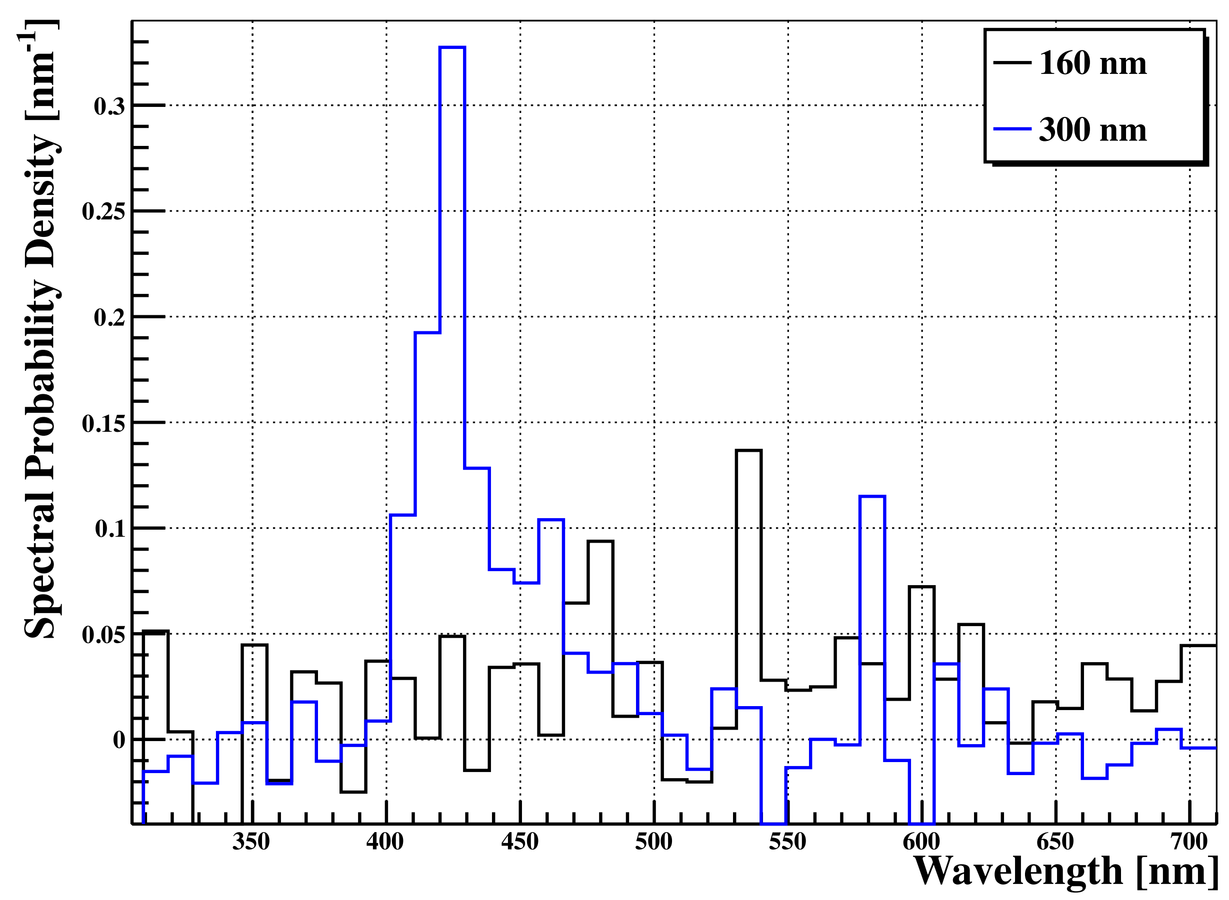
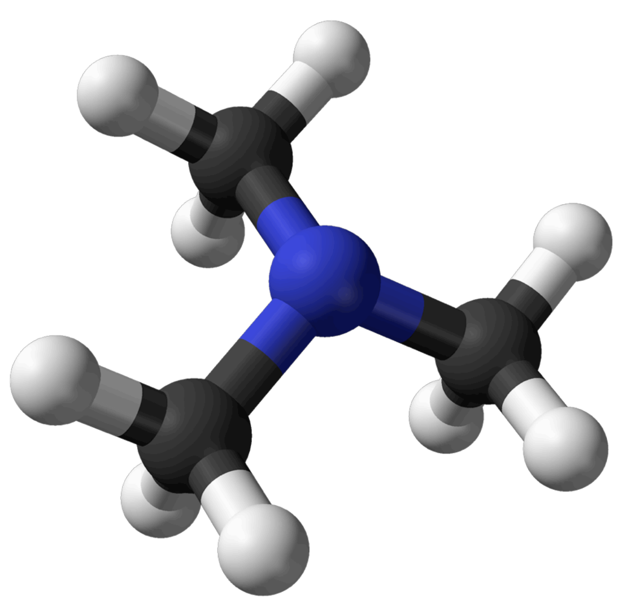
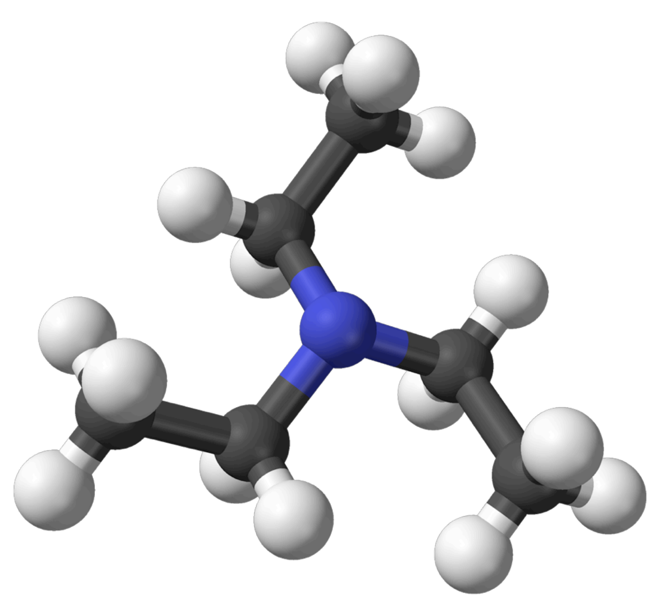


Two Birds With One Stone

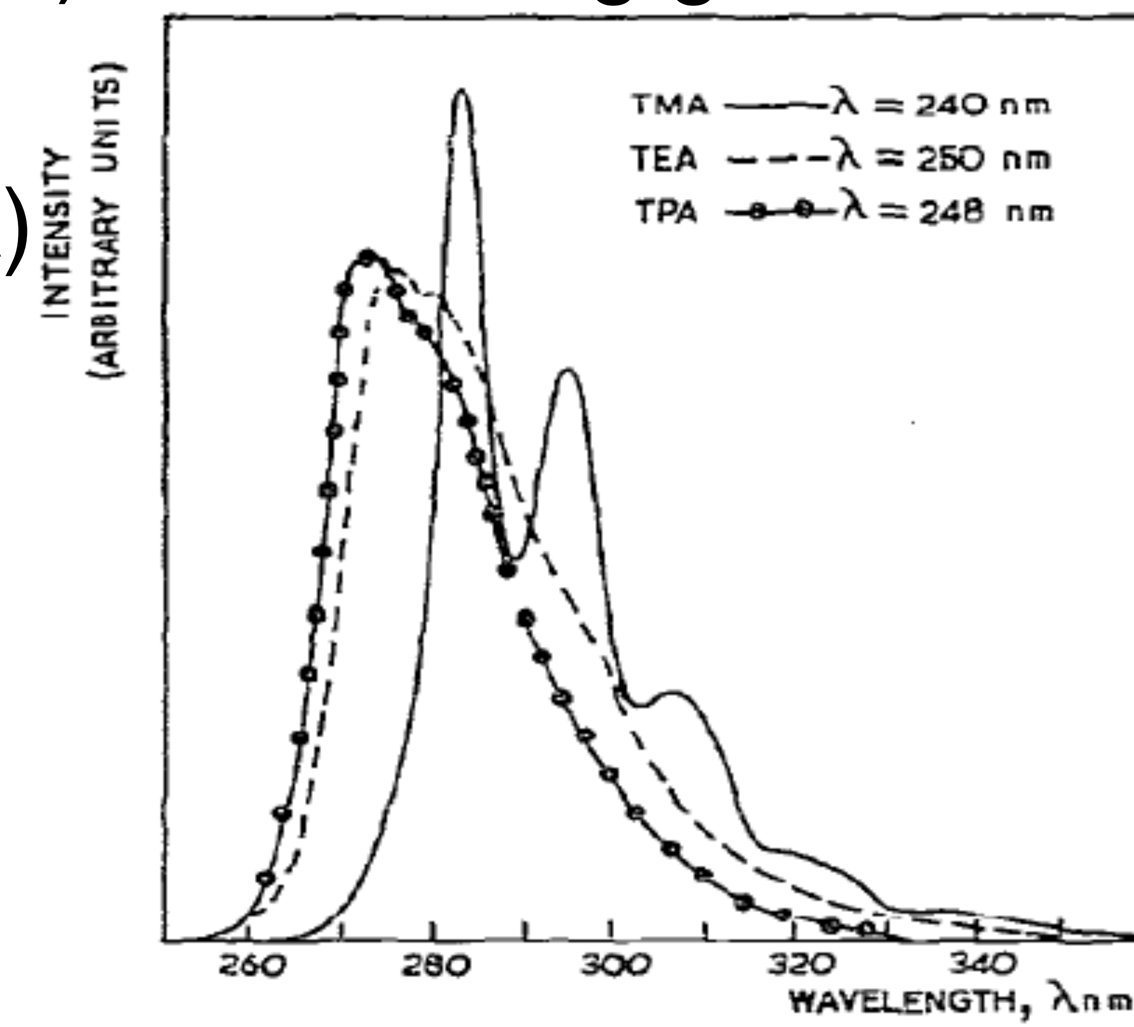
- To extract the CR signal from a HPXe gas detector, we need two things:
  - Penning additive to convert excitations into ionizations
  - WLS that absorbs at 173 nm and fluoresces at ≈ 300 nm
- Provenance! Tri-methyl-amine (TMA) is a Penning gas known to fluoresce efficiently at 300 nm!
- also possible: Tri-*ethyl*-amine (TEA)



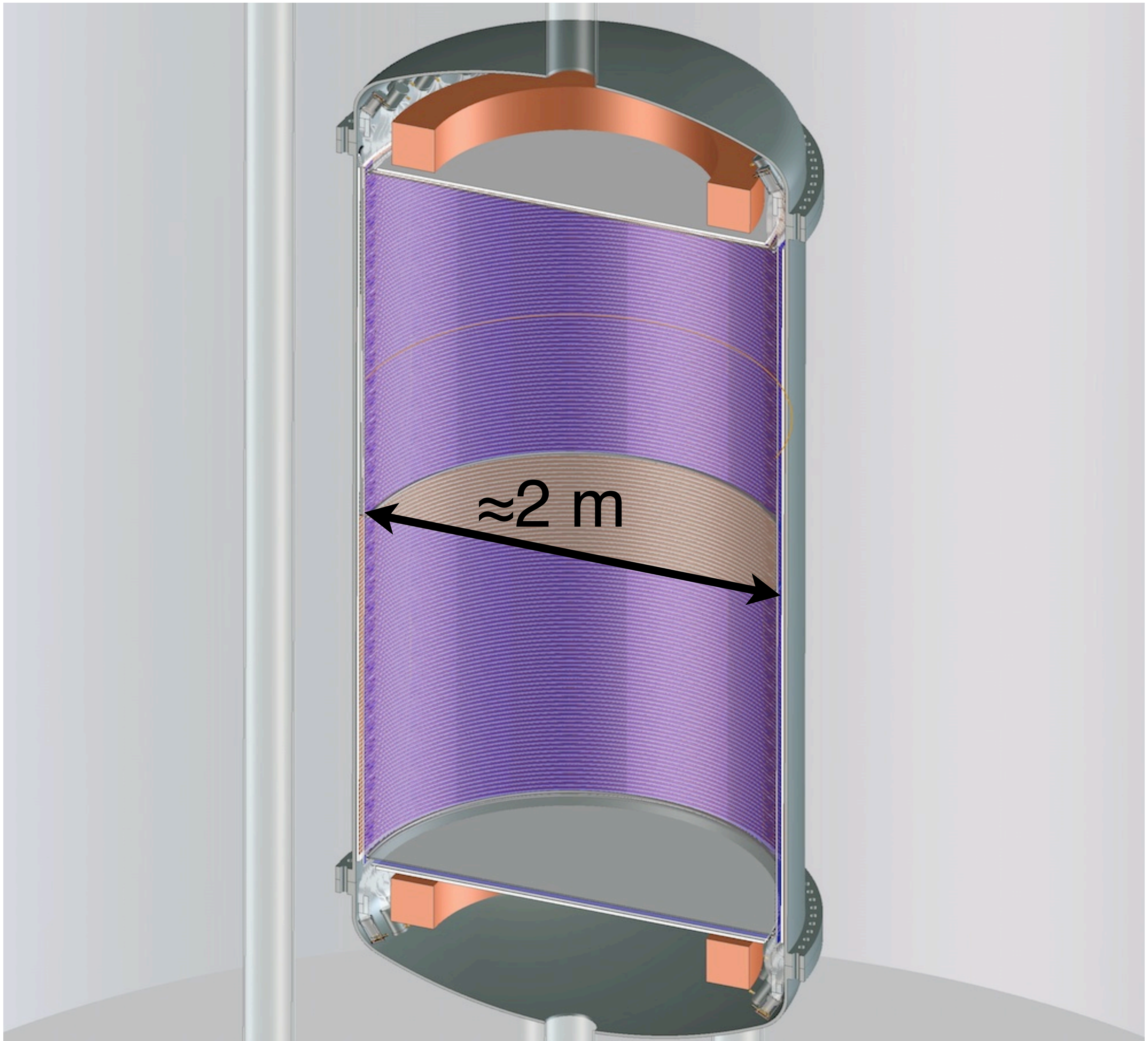
TMA



TEA



What Might This Look Like?



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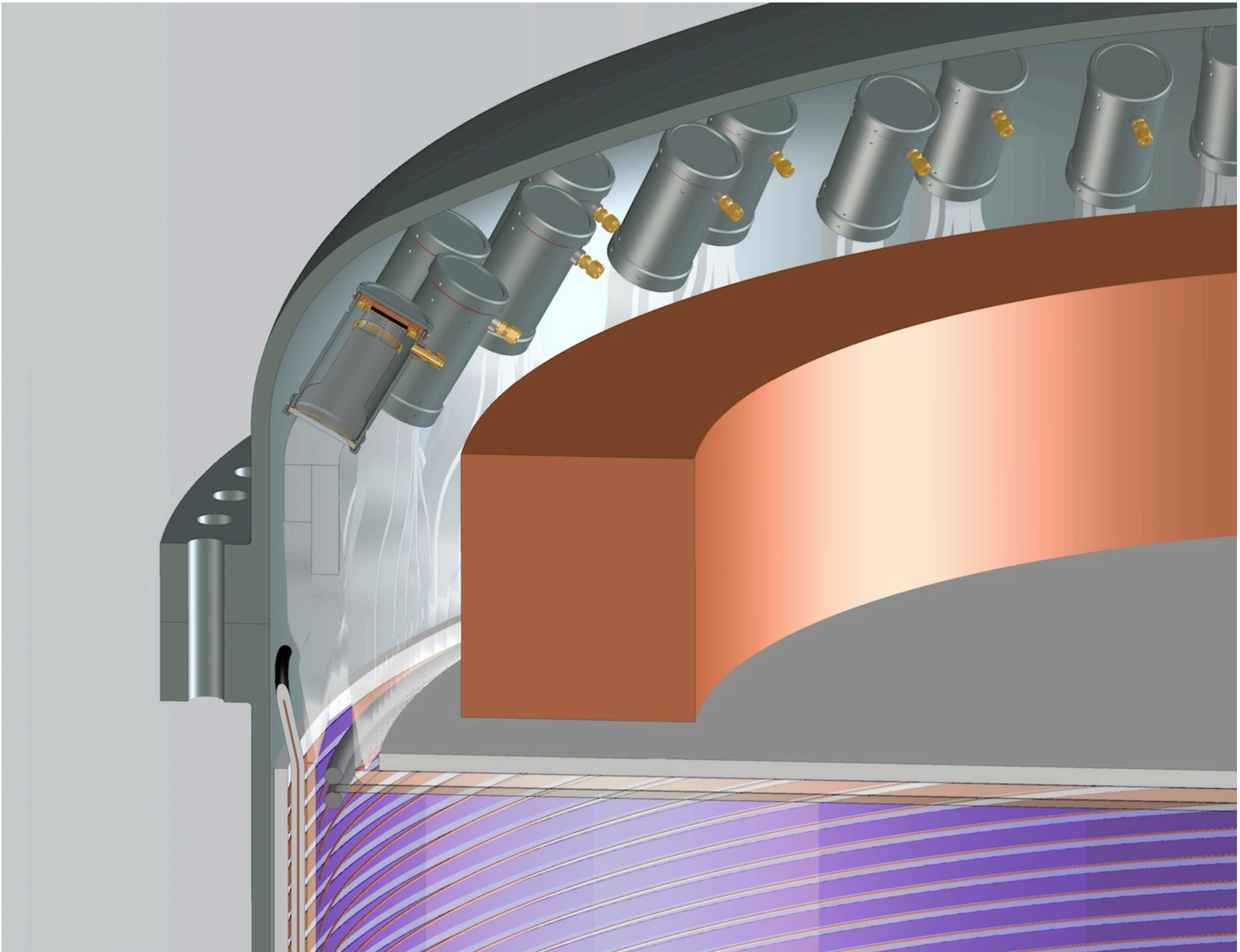

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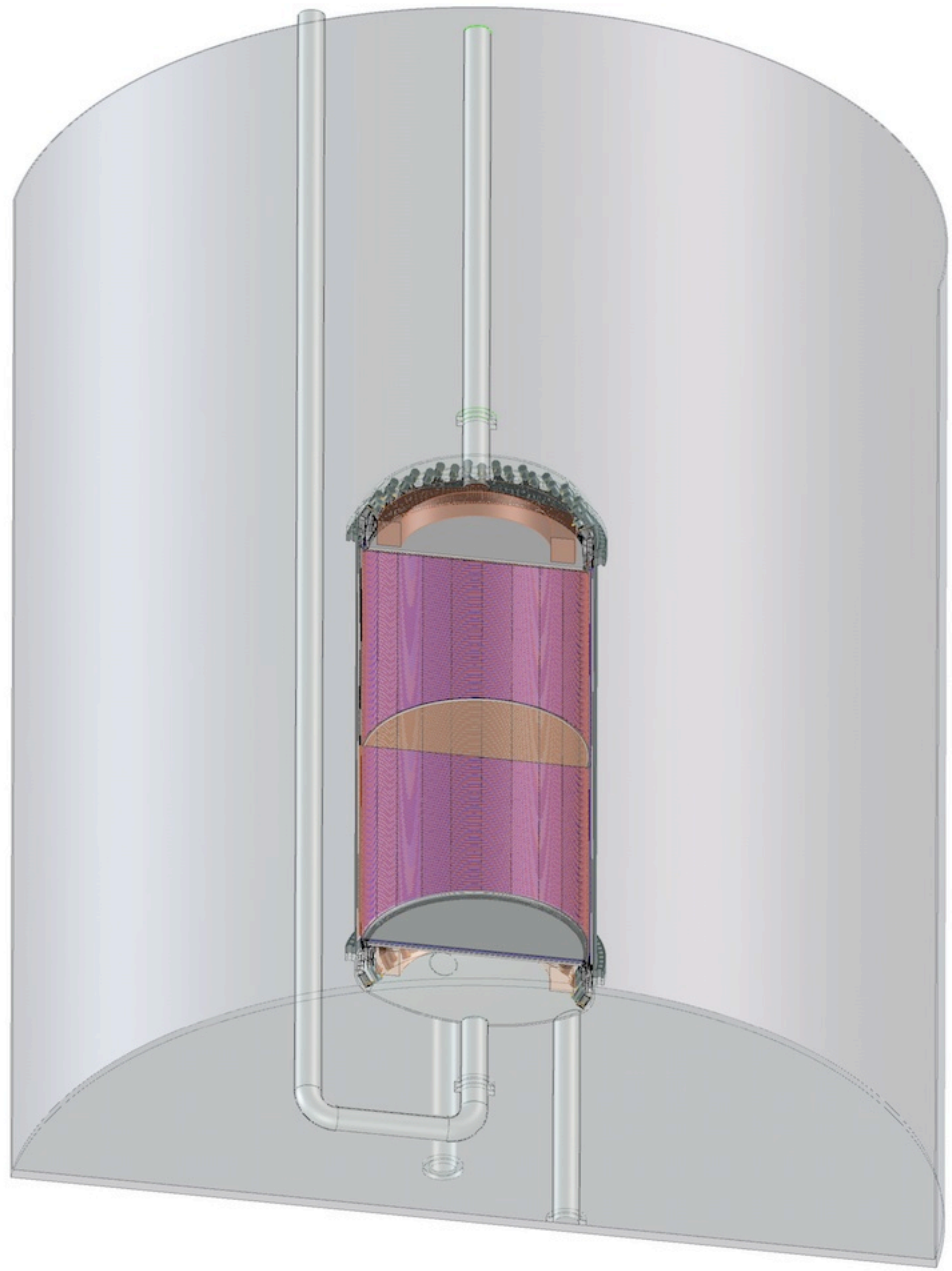
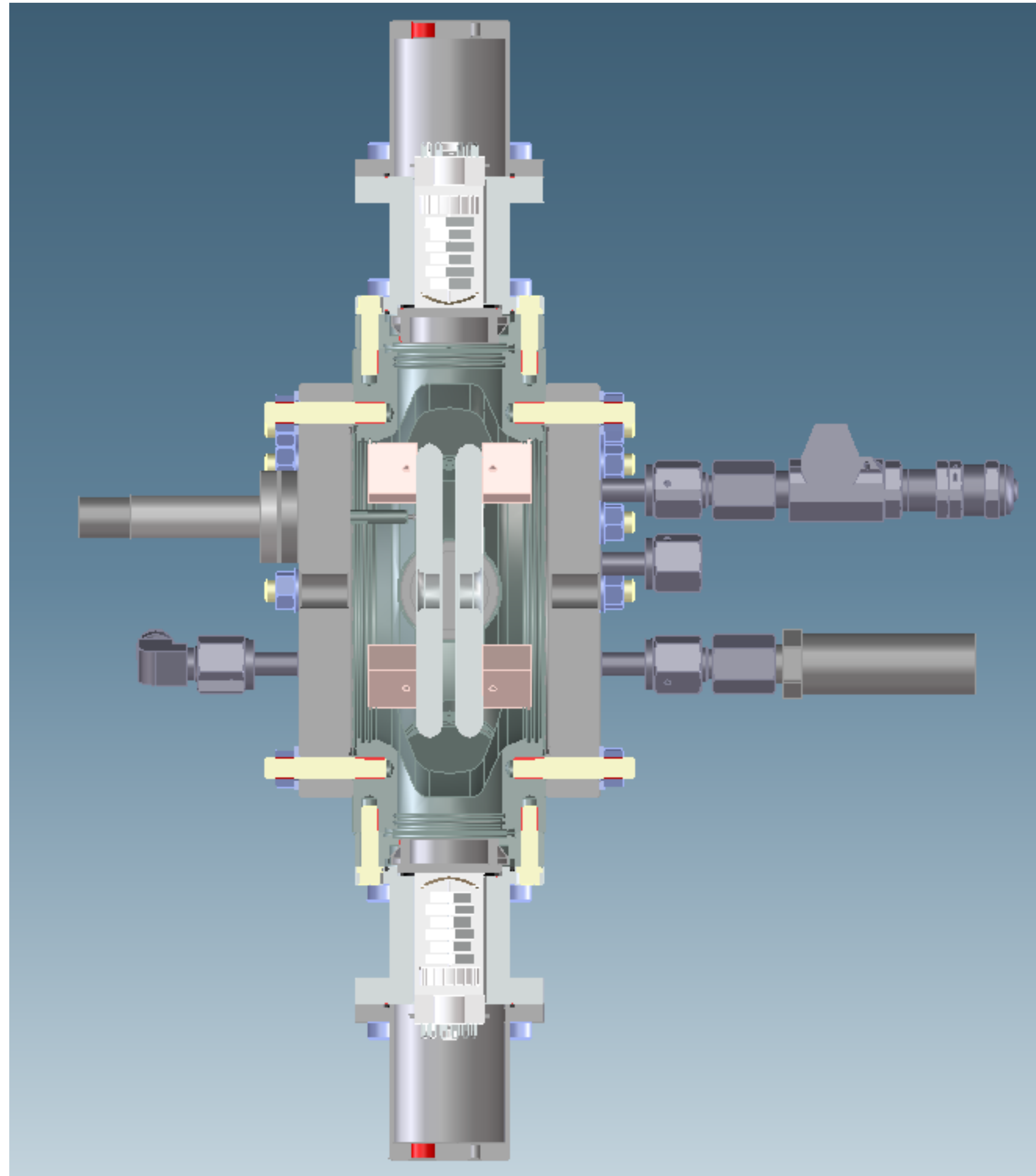


Shorter Term R&D

- The "TEA Pot"
- Measures basic response characteristics
    - Parallel-plate ionization chamber with optical sensing using 4 PMTs that look at the gap from the sides
    - Will measure both light and charge as functions of density, electric field, and fraction of TMA/TEA



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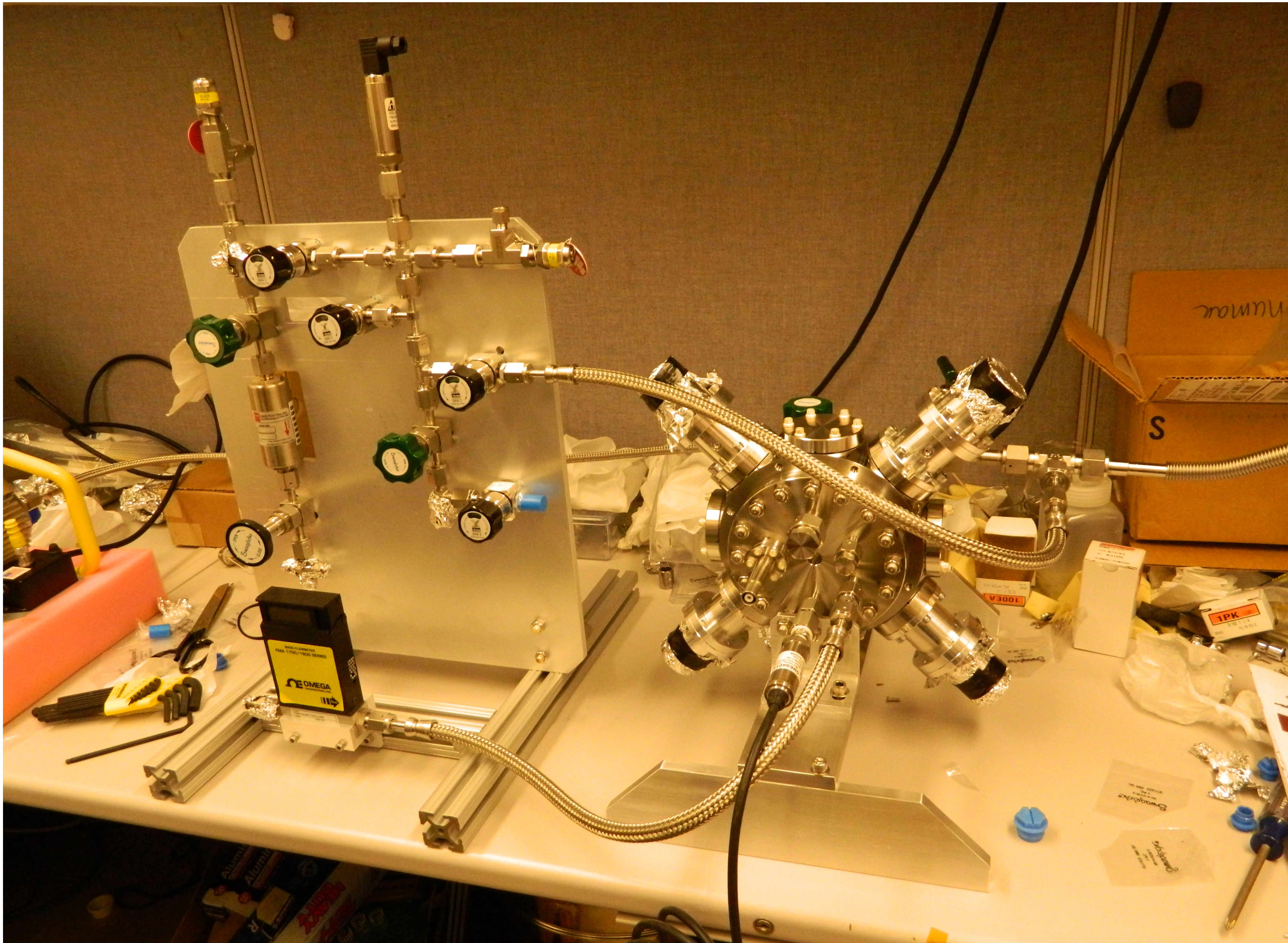

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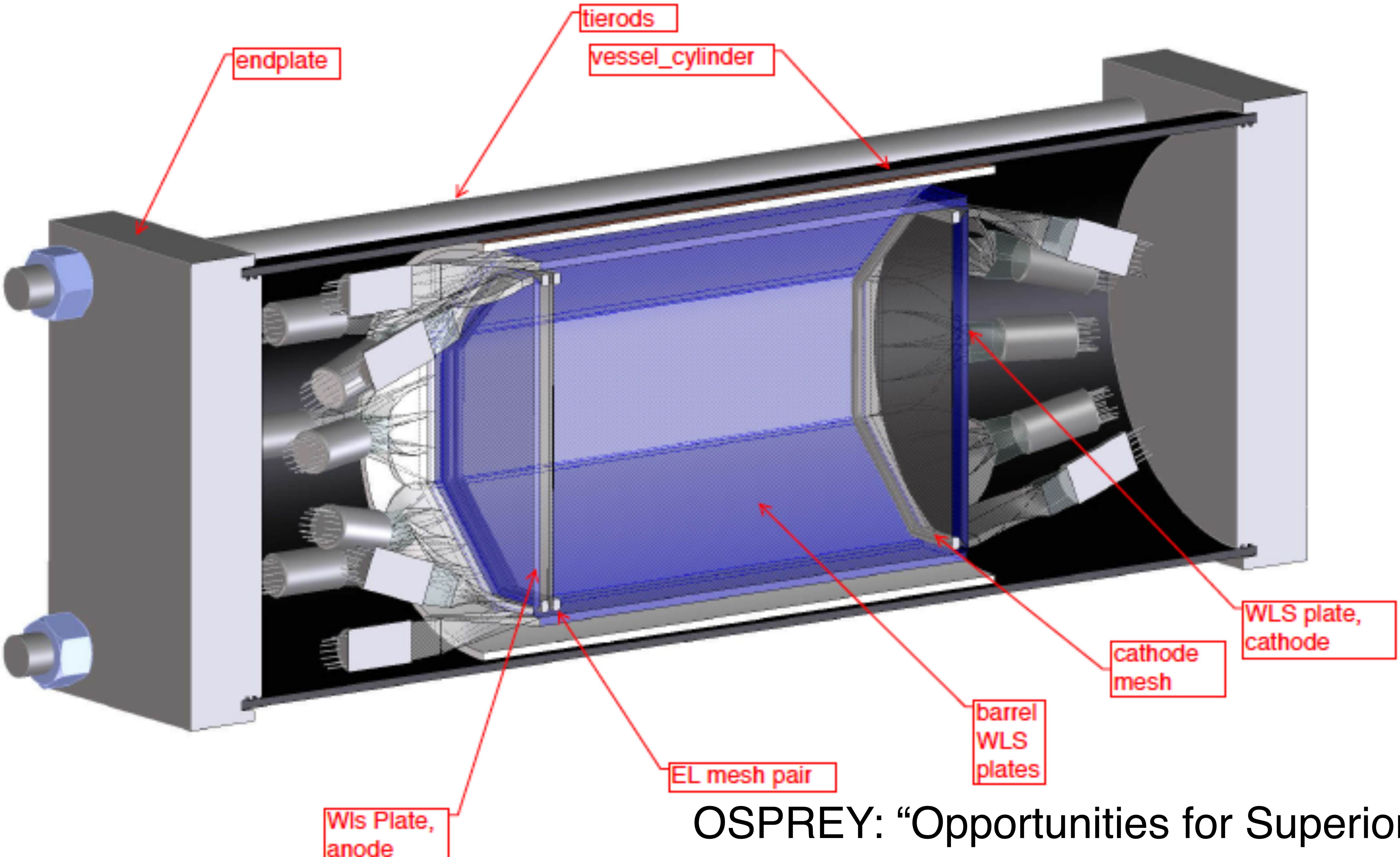

OSPREY: “Opportunities for Superior Performance in Rare Event Yields”

Conclusions

- This is a really unusual way to get at dark matter directionality
- Each step is quite plausible, but there are several unknowns to be addressed:
  - Penning efficiency of TMA?
  - Fluorescence efficiency of TMA in recombination?
  - Rate of ionic charge exchange?
  - Cooling rate of electrons after ionization?
- Initial simulations and R&D is underway!